Experimental Investigation on Permeable Concrete Based Mix Designs and Curing Methods

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Abstract— Permeable concrete is one of the modern technologies or invention in concrete technology. Permeable concrete is an innovative approach to control, manage and treat the stormwater runoff. Permeable concrete is the unique type of concrete which contains interconnected voids, these voids or pores allows storm and rainwater to percolate underground through it. Thus, permeable concrete is the best way to solve or minimize problems like waterlogging, low groundwater table. Permeable concrete mostly used as a paving material but it also may use for many different purposes other than pavement like tennis court, fish hatcheries, zoo, walkways, use of permeable concrete inside paver blocks, noise barriers, slope stabilization. The Methodology, as well as various test procedures, are mentioned, the test methods adopted to determine the properties of materials such as aggregate are impact test, flakiness index and elongation index, specific gravity, and water absorption of aggregate. The test methods adopted to determine the properties of fresh and hardened concrete are Slump Cone Test, Compressive strength Test, Flexural strength test. 10 mm and 20 mm coarse aggregate also SIKA-Aer as an air-entraining agent, and BASF MasterPolyheed as mid-range water-reducing admixture is used for preparing the Mix of permeable concrete. A unique method of Curing called as Internal Curing Method is used to cure the concrete. Internal curing and Immersion curing is given to the Trail Mixes, and their difference is also compared.

Keywords: Permeable Concrete, Internal Curing, Compressive Strength Test, Flexural Strength Test, Strom Water Management

I. INTRODUCTION

A. General

Permeable concrete is an environmentally friendly and sustainable infrastructure with benefits such as stormwater reduction, river peak flow rate reduction, groundwater recharge, pollutant abatement, heat island mitigation, noise reduction, and skid reduction. Typical applications of permeable concrete pavements include vehicle parking areas, sidewalks, pathways, driveways, and alleys. Permeable concrete allows rainfall to be drained and to percolate through the concrete to the subgrade materials, thereby reducing stormwater runoff and, at the same time, recharging the groundwater.

A permeable concrete mixture contains little or no sand, creating a substantial void content. Water to cement ratios between 0.27 to 0.30 are used with proper inclusion of chemical admixtures. Slump values or workability are usually less than 20 mm. The range of porosity commonly reported for permeable concrete is 15 to 30%, and this depends on the compaction method adopted. The permeability of permeable concrete varies from 120 litres/m^2/min to 320 litres/m^2/min. However, the strength of the material is relatively low because of its porosity. The compressive strength of the material can only reach about 20 Mpa to 30 MPa. The flexural strength of permeable concrete varies from 1 Mpa to 3.8 Mpa. The density of aggregates used for permeable concrete varies from 1600 kg/m^3 to 2000 kg/m^3.

A. Advantages of Permeable Concrete

- Concrete has a high porosity used for a flat concrete surface that allows water to pass through it.
- Unique surface finishes and enhance traction provides better skids resistance to light traffic at the time of rainfall.
- Reduce development cost with a smaller capacity of stormwater drainage and water harvesting arrangements.
- The permeable concrete pavement material has holes or voids that can collect heat such pavement and can adjust the temperature and humidity of the earth surface. It also reduces the heat island effect.
- It improves water quality and helps in groundwater recharge.
- It reduces the need for big infrastructures for water storage and reduces the overall cost.
- Since permeable pavements are available in various sizes, designs and colours, it can complement any architectural design or concepts.
- The permeable concrete pavements can absorb the noise of vehicles which create a silent and comfortable environment
- In rainy days the concrete pavements have no flash on the surface and do not shine at night. These improve the comfort and safety of drivers.
- To solve traffic jam problems in highly developed areas due to the problem of waterlogging.

B. Disadvantages of Permeable Concrete

- While this pavement is an excellent option for certain situations, it may not always be a viable choice. Because permeable concrete has a rough-textured, honeycombed surface, moderate amounts of surface ravelling are normal. It can be a problem on heavily travelled roadways. This is the main reason that the permeable concrete is not used for high-traffic pavements, such as highways, is surface ravelling.
- The maintenance requirements of permeable pavements are quite difficult.
- The permeable concrete is generally subjected to the clogging if the water present in the void doesn't drain out properly. The sand and fine particles which accumulate in the voids should be removed with the help of industrial vacuum unless the water and pollutant

to run off the surfaces, defeating the purpose of the permeable concrete pavements

C. Aims and Objectives

This experiment aims to prepare various mix designs by using various combinations of ingredients to obtain the economical mix design having more characteristics strength, good drainage property, economical curing method, low maintenance cost and also find out the optimum amount of the superplasticizers.

II. LITERATURE REVIEW

Terry Lucke1, Jo Divine [2017] Altered the natural characteristics of a drainage basin through urbanization can impose dramatic changes on the movement and storage of water within the catchment. As permeable pavements are specifically designed to promote the infiltration of stormwater through the paving and structure, they can be used to promote infiltration and groundwater recharge, while decreasing stormwater runoff volumes and flowrates from the catchment. The use of permeable pavements is seen as a good option in many stormwater management and environmental benefits.

Dr G. Vijayakumar [2013] found out that the replacement of cement by 20 %, 30 % and 40 % glass powder increases the compressive strength by 19.60 %, 25.30 % and 33.70 % respectively. In contrast, replacement of cement by 40 % glass powder increases the split- tensile strength by 4.40 % respectively, and replacement of cement by 20 %, 30 % and 40 % glass powder increases the flexural strength by 83.07 %, 99.07 % and 100 % respectively.

Lee M.J., Lee M.G., Huang Y., Chiang C. L [2013] have studied the purification study of permeable concrete pavement. In this paper emphasis more given on water quality and pollutants leached from permeable concrete. This primary aim to study the permeable concrete pavement by pollutants such as acid rain, seawater or waste lubricants oil. The result shows that pollutants and water purification of permeable Concrete pavement both significantly improved in the acid rain, seawater or waste motor oil test. A dilute H_2SO_4 solution (pH value 2.0) after the permeable system could significantly enhance its pH value 6.5 above. So permeable concrete pavement is valuable for road design and hydrologic consideration. The above study demonstrates that permeable Concrete specimen shows that the water penetration increases as the duration increases but the compression test and flexural test remain unchanged as the duration increases. Seawater (salt content 3.6 %) after the permeable Concrete pavement system the salt content is 0.1 % at the sub-base layer (soil) but remain unchanged at base layer (gravel). Similarly, the effect of dilute H_2SO_4 solution (pH = 2.0) after the permeable Concrete pavement test box its pH value is 6.93. In this case, oil acid effect is much low in the sub-base layer as compression to the base layer. In the case of waster, motor oil with certain water after the permeable concrete pavement text box could significantly reduce oil content to 1 %. In this case, the permeable concrete sub-base layer has taken a vital role in removing oil capacity. The test result shows that water purification and pollutant of permeable concrete pavement both significantly improved in the acid rain, seawater or waste lubricating oil test.

Kevern J.T., Schaefer R [2009] studied the method of curing permeable concrete by covering it with plastic for 7 days, although no studies have been performed to determine if that is sufficient or even required.

III. METHODOLOGY

A. Materials used

- Cementitious material - As in traditional concreting, Portland cement and blended cement may be used in permeable concrete. Also, supplementary cementitious materials such as fly ash, pozzolans, and ground-granulated blast furnace slag may be used. Testing materials beforehand through Trial batching is strongly recommended so that properties that can be important to performance (setting time, rate of strength development, porosity, and permeability, among others) can be determined. In this experiment, OPC 53-grade cement is used for all the Mix Designs.
- Water – the water is the same as used in any other types of concrete. It should be free from any suspended impurities.
- Aggregate – generally use of fine aggregate, i.e. sand in the concrete Mix makes the concrete less permeable as it fills the void in it. But the use of a little amount of sand in concrete Mix does not reduce the permeability of the concrete to a greater extent. The maximum size of aggregate used for permeable concrete is limited to 20 mm, i.e. metal 1 and metal 2 aggregates. Use of more substantial size of aggregate makes the surface of the concrete rough, and it leads to more surface revelling this happens very less in case of the smaller size of aggregate.
- Rounded aggregates give more permeability but give less bonding strength. The angular aggregates are suitable for these types of concrete as it gives adequate bonding strength and characteristics strength. From the previous researches, it is found out that the aggregate to cement ratio in this type of concrete fall between 3:1 to 8:1.
- In this experiment, angular aggregates of size 10 mm and 20 mm for all Trial Mixes The aggregate to cement ratio, i.e. A/C is 4.26:1.
- Admixtures - Chemical admixtures play a significant role in paste/mortar quality, which ultimately determines the quality of permeable concrete. In this experiment, water-reducing admixtures, i.e. superplasticizer, is used for lowering w/c ratio and increasing the strength of paste or mortar and modifying the setting properties of concrete concerning ambient conditions and also Air Entraining Admixture to improve the freeze/thaw durability of the paste/mortar.
- Other speciality products such as Viscosity Modifying Admixtures (VMA), latex-based admixtures, or water repellents may be used to ease placement, compaction and improve placement speed. Water repellents have a positive impact on overall durability. Colour/pigment additives in powdered or liquid form can be used for the production of coloured permeable concrete. In general,

it is recommended to use integral colourants as there is always initial ravelling when a structure is put in service. External surface paints, if not applied correctly, can also reduce the permeability of the pavement.

B. Test to be conducted

Several tests on aggregate and cement are conducted to determine the suitability of the materials for the concrete mixture. The test conducted on aggregate are specific gravity and water absorption of aggregate, aggregate impact value, flakiness index and elongation index, abrasion test of aggregate and the test conducted on cement is fineness test, setting tine, consistency test as well as field test conducted on the ingredients.

The workability test, such as the slump cone test is conducted on fresh concrete and compressive strength test and flexural strength test is conducted on hardened concrete. The results of these tests are given below.

C. Curing methods

The curing aims to restrict the loss of moisture from the concrete and maintain an appropriate temperature inside the mix. In this experiment, two methods of curings are used, i.e. Internal curing method and immersion curing method.

– Internal curing method - Pervious concrete is always placed on a pre-wet sub-base, which provides additional moisture for curing. As the pervious concrete itself contains many air voids, the exposed surface area that provides for the evaporation of mixing water is higher than that of conventional concrete. It is necessary to protect the concrete being placed as soon as possible and prevent excessive moisture loss, which may result in the reduced performance of the concrete. It is recommended to lightly mist the concrete surface before applying the protective plastic sheet. The plastic sheet should be placed over the surface immediately as the concrete is compacted, or no longer than 15 min after placement of the concrete. Placing the plastic sheet above the concrete surface reduces the moisture loss and extend the hydration time necessary for cementitious materials and achieve the requirements of the curing process.

– The benefits of internally cured concrete include a reduction in self-generated shrinkage, a reduction in the rate of drying shrinkage, reduction of elastic modulus, and improved hydration. In addition to these benefits, reduction in unit weight, increase in strength, and reduction of coefficient of thermal expansion add to a positive impact on slab fatigue. Reduction of the coefficient of thermal expansion is associated with cracking initiating both from the top and the bottom of the slab. There's also a potential for reducing the opening of shrinkage cracks, which simultaneously improves the shear transferability of the cracks and joints which leads to higher load transfer efficiency and longer service life.

Fig. 1: Internal curing for permeable concrete

– Immersion curing method – In this method of curing the test specimens are kept at a place which is free from vibrations, in the moist air of at least 90% relative humidity and at a temperature of 27° ± 2°C for 24 hours ± 1/2 hour from the time of addition of water to the dry ingredients. After this period, specimens are marked and taken out from the moulds and immediately submerged in clean, fresh water and kept there until 24 hours just before the test is to be conducted. The water in which test specimens are submerged is changed at an interval of seven days and is maintained at a temperature of 27° ± 2°C. The specimens are not to be allowed to become dry at any time until they have been tested. The test specimens are stored on the site at a place free from vibration, for 24 hours ± 1/2 hours from the time of addition of water to the other ingredients. The temperature of the place of storage should be within the range of 22° to 32°C. After 24 hours, they should be removed from the moulds, stored in clean water at a temperature of 22° to 30°C until they are transported to the testing laboratory. The Specimens should be sent to the testing laboratory well packed in damp sand, damp sacks to arrive the testing laboratory in a damp condition not less than 24 hours before the time of the test. At arrival, specimens are stored in water at a temperature of 27° ± 2°C until the time of the test. A record should be maintained of the daily maximum, and minimum temperature both during the period of specimens remain on the site and in the laboratory, particularly in cold-weather regions.

D. Mix Design

In this experiment, the mix design for M20 grade of concrete is made by referring to IS:10262-2009 and the proportion of fine aggregate are replaced with coarse aggregates. In this experiment separate mix designs by i) using only 10 mm aggregates and by ii) using 10 mm + 20 mm aggregates are made by using the admixtures mentioned above. The result obtained from these proportions is mentioned in the result section. Following are the mix proportions for permeable concrete (see Table No. 1).

Sr No.	Mix name	Cement in kg/m^3	Coarse aggregate in kg/m^3		Water in kg/m^3	Admixture in kg/m^3	
			10 mm	20 mm		Superplasticizer	air-entraining
1	Trial Mix 1	443	1887	0	186.06	4.43	0
2	Trial Miz 2	443	598.05	1289.13	186.06	4.43	0
3	Trail Mix 3	443	598.05	1289.13	132.9	0.9303	1.772
4	Trail Mix 4	443	1887	0	132.9	0.7531	1.772

Table 1: Mix Proportions

IV. RESULTS

A. *Results For Flexural Strength Test*

The Flexural Strength of permeable concrete is generally various from 1 Mpa to 3.8 Mpa. Many factors influence the flexural strength, particularly the degree of compaction, porosity, and the aggregate to cement (A/C) ratio. The result of both curing methods is given in the table below.

Method of curing	Trail Mix 3	Trail Mix 4
Internal curing	1.48	1.15
Immersion curing	1.106	1.06

Table 2: Flexural Strength Test Result in Mpa

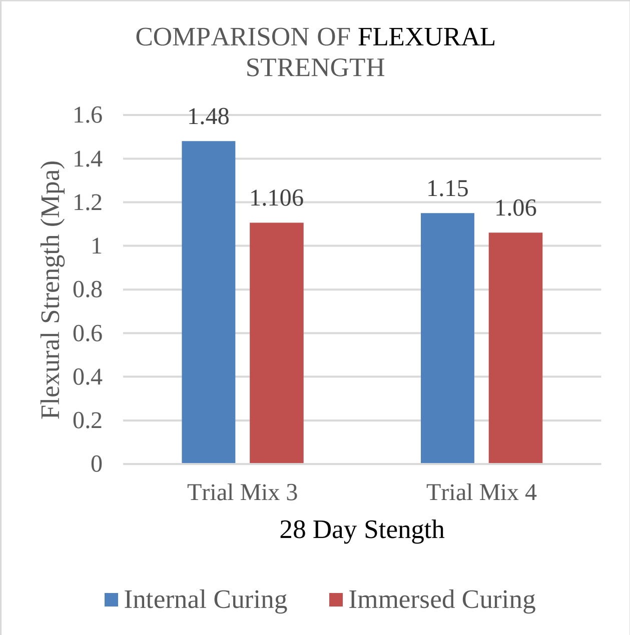

Fig. 1: Comparison of Flexural Strength

B. *Result for Compressive Strength Test*

It is essential to carry out the compressive strength of concrete. In the case of Permeable concrete, the compressive strength varies from 3.5 Mpa to 28 Mpa. The results for permeable concrete cured by internal curing method and Immersion curing method are given in the tables below.

Method of Curing	7 Days	14 Days	28 Days
Internal curing method	7.51	10.82	13.78
Immersion curing method	5.38	9.43	12.07

Table 3: Compressive Strength Result for Trial Mix 3 in Mpa

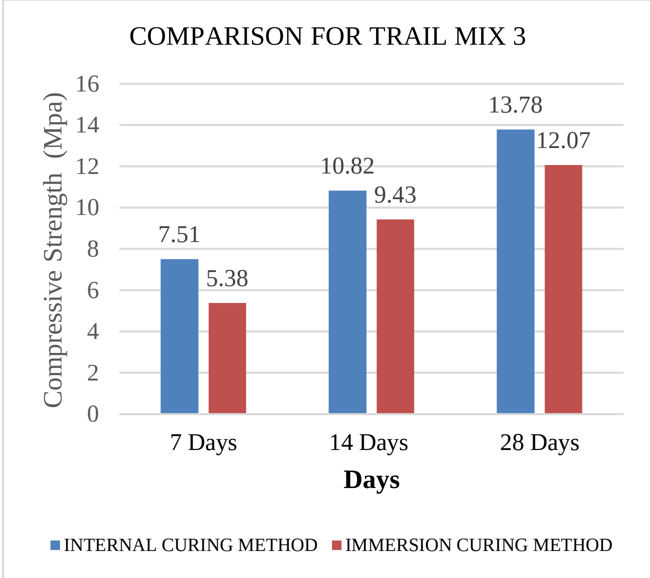

Fig. 3: Compressive Strength for Trial Mix 3

Method of Curing	7 Days	14 Days	28 Days
Internal curing method	6.39	9.56	13.30
Immersion curing method	5.99	8.16	10.77

Table 4: Compressive Strength Result for Trial Mix 4 in Mpa

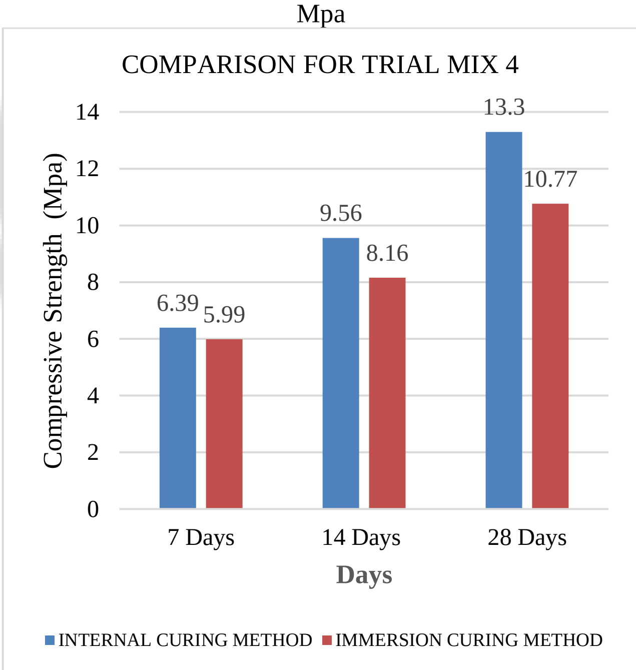

Fig. 2: Compressive Strength for Trial Mix 4

C. *Conclusion*

This report describes the mix design of permeable concrete, permeable concrete pavement and its types, needs and its present applications. This report also looked at various literature reviews and studies conducted on permeable concrete mix designs and permeable concrete pavement systems. The water quality and life span aspects were outlined for permeable pavement systems. Also, the different methods used for curing that are, internal curing method and immersion curing are also stated, and test results regarding both the curing methods are briefly outlined in the report.

In this experiment, we can conclude that the different sizes of aggregate and W/C ratio and also the amount of admixture gives us different test results. Combination of different size of aggregate gives more result as compared to the concrete made with an only single size of aggregate. Internal curing method gives more result as compared to curring by immersion method and also saves the water required for curing. The texture of the concrete is smooth when more amount of small size aggregates are used.

D. Future Scope

Till date, the application of permeable pavement has limited to some specific applications like parking lots, low traffic volume roads. Future research may allow for new and innovative applications such as village roads, airport runways. Permeable pavements generally have low strength, but by increasing its strength and improving the properties, Permeable pavements can be used for the construction of heavy traffic roads like Urban roads, Highway Shoulders. Generally, in a densely populated area, less land space exists, so the roads aren't properly arranged as well as the surface drainage facilities aren't provided suitably. So, in rainy seasons the problems of water clogging arise. So, for these areas, permeable pavement can become a good option. Jogging tracks or walkways in parks or gardens are constructed of compacted soils, But in rainy seasons these roads become muddy which cannot be used for their intended purpose. It causes various problems for pedestrians. So, for this type of situations, permeable pavements can be proven advantageous.

A porous sub-base can highly increase the infiltration rate through the system. But in practice placement of the pavement over a highly porous material (like gravel) potentially leads to a reduction in its bearing capacity. Therefore, more studies on proper porous sub-base are needed. As semi-arid areas are mainly in developing countries, due to the lack of financial sources, education and management, the maintenance of porous pavements might not be done regularly. It leads to a decrease in the working life of the pavement. Therefore, these matters should be taken into account to select the proper type of pavement in different places. Effect of other factors such as the erosion of the pavement under the climatic condition on the clogging process can be done in future studies.

V. REFERENCES

[1] Dr G.Vijayakumar, "Studies on Glass Powder as Partial Replacement of Cement in Concrete Production" International Journal of Engineering and Advanced Technology (IJEAT) ISSN 2250-2459, ISO 9001:2008, Volume 3, Issue 2, 2013.
[2] Wang, K., Cable, J. K., and Zhi, G., "Evaluation of Pavement Curing Effectiveness and Curing Effects on Concrete Properties," J. Mater. Civ. Eng., Vol. 18, pp. 377-389, 2006.
[3] Park, S., and Tia, M., "An Experimental Study on the WaterPurification Properties of Porous Concrete," Cem. Concr. Res., Vol. 34, pp. 177–184, 2004.
[4] Jain A.K. and Chouhan J.S, "Effect of shape of aggregate on compressive strength and permeability properties of pervious concrete", International Journal of Advanced Engineering Research and Studies, I (2012).
[5] Lee M.J., Lee M.G. Huang Y and Chiang C.L., "Purification study of pervious concrete pavement", International Journal of Engineering and Technology, (2013).
[6] IS 2386 – 1963 (Methods for test for aggregate and for concrete).
[7] IS 10262 – 2009 (Concrete Mix proportioning – guidelines).